Proton Decay of Analog States Formed in $^{119}Sn(p,n)^{119}Sb$†

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(Received 10 February 1975)

The proton decays of $T_>$ states in ^{119}Sb formed in the reaction $^{119}Sn(p,n)^{119}Sb$ (isobaric analog state) have been studied using a neutron-proton coincidence technique. Analogs of excited states are observed with a total strength which is approximately 50% of that of the cross section to the ground-state analog. These higher analog states decay predominantly with proton energies close to that of the ground-state analog decay.

The formation of isobaric analog states (IAS) by the (p,n) reaction usually is observed directly by detecting the outgoing neutron. Recently, it has been observed indirectly[1,2] via the proton decay $(\tilde{p})$ of the analog state.

For certain nuclei in the lead region the widths of analog states determined from the shape of the $\tilde{p}$ peak[3] are greater than those obtained from (p, p') resonance experiments[4] and (p,n) time-of-flight spectra.[5] Later, in the case of $^{209}Bi(p,n)^{209}Po$ (IAS), the cross section[6] to the ground-state (g.s.) analog was found to be less than half that determined from $\tilde{p}$ data.[7] It appears that these differences cannot be attributed to experimental difficulties.

To explain these results, Grimes *et al.*[6] suggest the population of analogs of excited states which decay by proton emission with energies close to that of the ground-state proton decay. However, Fielding *et al.*[8] have suggested that the formation of excited-state analogs falls off markedly for $A > 90$. Indeed, Grimes *et al.* also found no direct evidence for excited-state analogs, although they noted that the neutron background observed would mask a yield as high as 2 mb to a single state.

In this Letter, we present evidence for the population of excited-state analogs in the reaction $^{119}Sn(p,n\tilde{p})^{118}Sn$ with a strength which suggests that it may be more important in heavy nuclei than the (p,n) data indicate.

Neutrons were detected by an array of NE213 liquid scintillators[9] set at 12° intervals, and 40 cm from the target. The neutron time of flight (TOF) was recorded in coincidence with proton signals in either of two E-Veto telescopes placed near the target. Fast-timing and pulse-shape-discrimination techniques produced clean TOF spectra with a resolution of 1.7 nsec. At 17-MeV incident energy, this corresponds to a g.s. IAS neutron peak width of about 600 keV. Neutron spectra gated by protons in the energy region expected for IAS decay were monitored on-line, while all TOF-proton coincidences were recorded event by event on magnetic tape.

Figure 1(a) shows a TOF spectrum at 48° at an incident energy of 17 MeV, gated by protons with energies near 7.21 MeV, the $\tilde{p}$ energy of the g.s. analog. In addition to a strong peak, $n_{\rm I}$, due to exciting the g.s. analog, a group, $n_{\rm II}$, is seen in the energy region corresponding to exciting analogs of several states in ^{119}Sn near 1 MeV. Figure 1(b) shows proton spectra, gated by $n_{\rm I}$ and $n_{\rm II}$ separately, obtained by replaying the raw-data tapes.

As expected, the 7.2-MeV peak dominates the $n_{\rm I}$-gated spectrum, whereas in the $n_{\rm II}$-gated spectrum several peaks are seen presenting further strong evidence for the population of analogs of excited states of ^{119}Sn. Peaks at 8.0–8.5 MeV correspond to proton decays to the ^{118}Sn g.s., and the lower-energy peaks to decays to the 1.23-MeV 2^+ state (see Fig. 2).

The arrows in Fig. 1(b) indicate the expected proton energies based on the nature of the low-lying states in ^{119}Sn (see Fig. 2). The g.s. $\frac{1}{2}^+$, 0.024-MeV $\frac{3}{2}^+$, 0.089-MeV $\frac{11}{2}^-$, and 0.787-MeV $\frac{7}{2}^+$ states are nearly pure single quasiparticle (SQP) states,[10] and their analogs should decay mainly to the ^{118}Sn ground state. Most of the $d_{5/2}$ SQP state is contained in the 1.09-MeV $\frac{5}{2}^+$ state, the remainder being shared between the $\frac{5}{2}^+$ states at 0.921 and 1.35 MeV. These three $\frac{5}{2}^+$ states and the $\frac{3}{2}^+$ state at 0.920 MeV are seen strongly in Coulomb excitation and account for the strength of the 2^+ core excitation coupled to an $s_{1/2}$ neutron.[11] The analogs of these four states, therefore, should have sizable decays widths to the first 2^+ state in ^{118}Sn.

As can be seen in Fig. 1(b), there is good evidence for proton decays to the 1.23-MeV 2^+ state of ^{118}Sn, which suggests that the (p,n) reaction

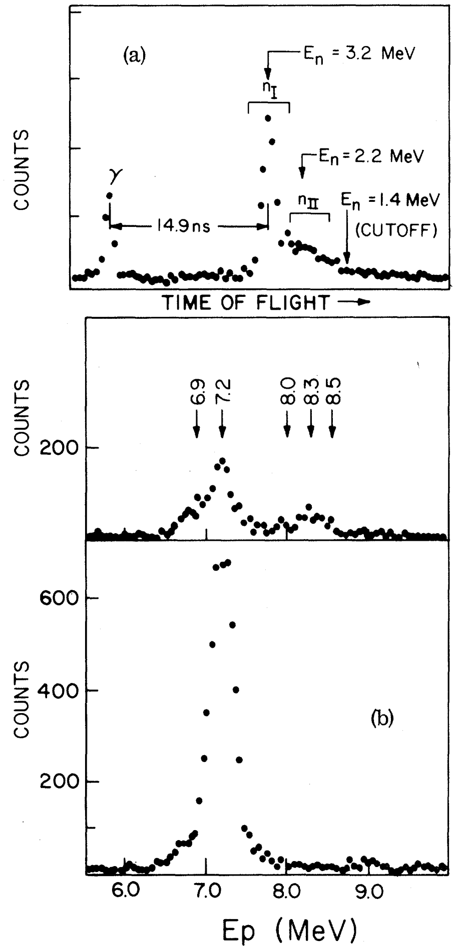

FIG. 1. (a) Neutron time-of-flight spectrum for the reaction $^{119}Sn(p,n\tilde{p})^{118}Sn$, taken at 48° and incident energy of 17 MeV, gated by protons with energies near 7.2 MeV. Population of the analog of the ^{119}Sn g.s. is indicated by the 3.2-MeV neutron peak n_{I}. The energy of the neutron group n_{II} corresponds to the population of analogs of states in ^{119}Sn at an excitation energy near 1 MeV. (b) Decay-proton spectrum in coincidence with n_{I} neutrons (lower curve) and n_{II} neutrons (upper curve). The arrows indicate several probable proton energies following the population of excited analogs of ^{119}Sn and their decays to either the ground (0^+) or first-excited states of ^{118}Sn.

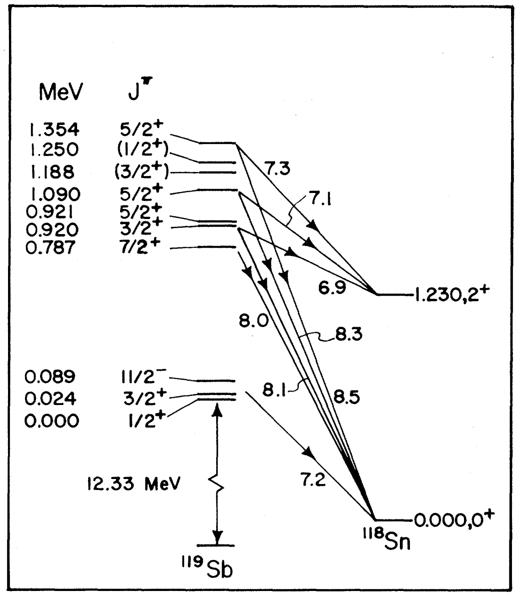

FIG. 2. Expected proton decay scheme (relative to the g.s. analog) of $T_{>}$ states of ^{119}Sb based on the known properties of the low-lying states of ^{119}Sn and ^{118}Sn (Refs. 10 and 11).

excites the analogs of the 2^+ core-excitation states quite strongly. That many of these states also have a SQP component is evidenced by their decays to the ground state. In general, a more detailed analysis, gating on a narrow band of proton energies, shows a strong correlation with different regions of the neutron spectra consistent with the present interpretation. For example, the neutron peak 0.9 MeV below the g.s. analog peak is most prominent when gated by a narrow band of proton energies centered at 6.9 MeV.

Taking into account the energy dependence of the neutron-detector efficiency, the relative population of the analogs of the ground and excited states was estimated by comparing $\tilde{p}$ spectra gated by the n_{I} and n_{II} groups, respectively. The results indicate that the $\tilde{p}$ contribution from excited IAS's is roughly 50% of that from the ground IAS. Furthermore, the majority of decays of these higher analog states are to the ^{118}Sn 2^+ states, which gives a large, broad $\tilde{p}$ group near 7.2 MeV, the decay energy of the g.s. analog. Thus a measurement of the ungated proton decay would considerably overestimate the width and yield of the ground IAS.

We have not yet analyzed the data in terms of specific reaction mechanisms. The angular distribution of the yield to excited-state analogs suggests a direct process, but a sizable contribution from a compound-nucleus mechanism cannot be ruled out. Since the population of excited-state analogs in heavy nuclei is not seen in (p,n) studies, it may be that they are populated via their mixing with nearby $T_{<}$ continuum states which are excited either directly[12] or indirectly via the compound nucleus.[13] However, regardless of the mechanism, if the observed inelastic strength were distributed uniformly among the several unresolved excited states comprising the n_{II} group, this would put the strength for each state close to or below the limit of observation of most noncoincidence measurements.

The effects described here could account for at least part of the discrepancies found in the lead region, where the weak-coupling model works well. Some of the reported width and cross-section discrepancies for ^{207}Pb and ^{209}Bi, however, require an even larger excited-state contribution than is seen in ^{119}Sn. Furthermore, the width anomaly for ^{208}Pb remains[3] even at energies too low to populate excited-state analogs. Nevertheless, a careful comparison of measurements taken in an n-$\bar{p}$ coincidence experiment, such as the present one, with those taken in (p,n) and ungated $\bar{p}$ experiments should give valuable insight about the processes involved in the formation and decay of isobaric analog states.

†Work supported in part by the U. S. Atomic Energy Commission, Contract No. AT(11-1)-1265.

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Transitions between High-Spin Nuclear States*

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We have measured the energy spectra, angular correlations, and number of continuum γ rays following several heavy-ion reactions. A separation of the spectrum into yrast and statistical cascades is clearly indicated for the heavier product nuclei studied ($Z \gtrsim 50$), but is not so obvious for the lighter ones. The yrast cascades associated with three particular reaction channels have been interpreted to give moment-of-inertia values for the highest-spin states in these channels (up to $60\hbar$).

Studies of transitions between high-spin nuclear states can give information about moments of inertia, shapes, and other structural features of such nuclei. High spin values (up to $80\hbar$) can be brought into compound nuclei following heavy-ion reactions; however, γ-ray studies following such reactions have thus far produced information mainly on states having spins below $\sim 20\hbar$. The reason is that all the transitions between higher-spin states are too weak individually to be resolved, and thus comprise an apparent continuum. There were some early attempts to study this continuum,[1,2] but these studies have only recently been resumed.[3-6] In the present work, the energies, angular correlations, and number of continuum γ rays have been measured, and the information obtained from these quantities has been related directly to nuclear moments of inertia at angular momenta up to $60\hbar$.

We have studied mainly the reactions ^{82}Se(^{40}Ar, xn)$^{122-x}$Te and ^{126}Te(^{40}Ar, xn)$^{166-x}$Yb by using 183-MeV Ar beams from the Lawrence Berkeley Lab-